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Request for grant of a patent

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1.	Your reference	P04135GB
2.	Patent application number *(The Patent Office will fill this part in)*	0325699.7
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Charles Raymond LUFFMAN Dorfstrasse 22 15910 Staakow Germany
	Patents ADP number *(if you know it)*	8497836001
	If the applicant is a corporate body, give the country/state of its incorporation	
4.	Title of the invention	STRATOSPHERIC LIGHTER THAN AIR VEHICLE
5.	Name of your agent *(if you have one)*	LAURENCE SHAW & ASSOCIATES
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	1 Hagley Road Edgbaston Birmingham B16 8TG
	Patents ADP number *(if you know it)*	1362300l

		Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6.	Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.			

		Number of earlier UK application	Date of filing *(day / month / year)*
7.	Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute *(see note f)*		

8.	Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request? Answer YES if: a) any applicant named in part 3 is not an inventor, or b) there is an inventor who is not named as an	NO

0084852 04-Nov-03 0

Patents Form 1/77

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form		8
Description	27	
Claim(s)	4	
Abstract	1	
Drawing(s)	2 only	

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for a preliminary examination and search (Patents Form 9/77)

Request for a substantive examination (Patents Form 10/77)

Any other documents (please specify)

11. I/We request the grant of a patent on the basis of this application

Signature(s) Laurence Shaw & Associates
LAURENCE SHAW & ASSOCIATES Date 4/11/2003

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom Rupert Symons 0121 454 4962

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Agents ref: P04135GB

STRATOSPHERIC LIGHTER THAN AIR VEHICLE

This invention relates to lighter-than-air vehicles and in particular to such a vehicle for providing a stratospheric platform suitable for telecommunications and other electronic equipment operations.

The basic requirements for such a vehicle are as follows:

- able to fly autonomously by pre-programmed or remotely controlled autopilot signals from a ground station;
- launch from the ground station and ascend under free flight to operational height without damage or loss of operability;
- able to carry at least 1000 kg (1 tonne) payload in a manner suitable for the purpose;
- able to house and protect the payload from adverse environmental effects;
- able to provide sufficient power for operation of the payload systems;
- operation at 20 Km +/- 1 km above sea level;
- continuous free flight operation for periods not less than 30 days – 90 days as a goal;
- ability to remain within 1 km radius of a geostationary position at the operational height;
- able to descend under free flight to the ground station without damage;
- able to be captured from free flight at the ground station;
- able to be moored and held indefinitely at the ground station;
- able to withstand wind conditions whilst moored up to 50 kts without damage;
- able to withstand storm conditions whilst moored under winds gusting to 80 kts without breakaway;

- able to be maintained at the ground station using standard low reach equipment;
- able to be recovered safely to ground level following power system failure;
- able to be operated from ground station set-ups in locations typically accepted for normal aircraft operation;
- able to be packaged and delivered by road;
- able to be assembled, inflated and set up for operation at a ground station mooring site;
- able to achieve high utilisation compared with commercial aircraft;
- to have significantly lower costs (for purchase and operation) than a conventional airship able to operate at the same altitude with the same payload;

Lighter-than-air (LTA) vehicles, typically balloons, aerostats and airships, can be used as aerial platforms to carry various payload arrangements. Their slow speed plus ability to float without need for aerodynamic lift generation (to carry their weight) or disturbance of the surrounding atmosphere, quietly maintain station over a ground position with little effort for long periods of time and provide a stable, vibration free environment with all round unobstructed views of the surface below are advantages ideal for aerial surveillance or other area coverage roles. Recently over the last 10 years or so there has been purposeful interest to use LTA aircraft in the stratosphere as platforms for telecommunications and other electronic systems. This has not come to fruition yet due to the difficulties involved in making a suitable vehicle.

The idea evokes interest since at such heights LTA vehicles would be able to perform similar roles to satellites, although with very much reduced cost and better performance. Also, they could be recovered and re-deployed whenever conditions were suitable (an aspect too difficult and expensive for satellites to do generally) and

may be used as relay points for satellites, other aircraft or ground systems – to extend and enhance existing communication systems.

Currently, there are no commercial LTA vehicles able to fulfil the role outlined in the above basic requirements. Interest has led to proposals for extended airship use, since (to maintain a geostationary position – rather than drifting in the wind) directional control and flight against air currents, plus vertical drafts, are necessary. Tethered aerostats also have been considered, but the weight and deployment/recovery problems with such long tethers make these unsuitable and they are not able to maintain geostationary positions with sufficient accuracy. The tether also is a hazard to lower flying aircraft and is not easy to detect.

A basic problem that the vehicle must solve in order to attain and be capable of operation at the required altitude and be recoverable, is expansion of the lifting gas without rupture of the containment cell, or unwanted gas release. Expansion of the lifting gas will be considerable (about 15 times the volume of the initial ground level gas fill charge at the operating height).

For an airship to operate and be controllable it must maintain its basic shape and rigidity. Non-rigid airships do this by pressure stabilisation of the gas containment envelope (also the airship's hull). To avoid loss of gas, non-rigid airships use internal cells (ballonets) filled with air to keep the air separate and make up the fill deficit necessary when the airship is at low altitude. After filling, by pumping additional air into the ballonets the envelope is pressurised and by releasing air from the ballonets via valves an overpressure situation is avoided without releasing the lifting gas. Also, the super pressure generated is regulated via a control system to maintain constant levels. A ballonet sized with at least 93% of the envelope's capacity would be necessary for a

non-rigid airship to maintain adequate form throughout the ascent and descent. Discharge valves and blowers also must be provided of sufficient capacity to accommodate the respective rate of expansion or contraction of the gas during the climb and descent, depending on the vertical velocity and environmental effects. The power requirements and resultant weight of these systems will be of significant consequence.

A rigid airship, which allows its gas cells to expand freely and contract within the hull framework, would face similar problems – although blowers would be unnecessary. The main problem here is the size of the structure (and consequent weight) that results. An airship with about 350,000 to 400,000 m^3 capacity would be necessary to meet the above requirements.

Very large manned free balloon systems have been successfully used and are able to endure variable conditions over extended periods. Compared with airships, which are subject to super pressure levels to stabilise and stiffen their envelopes (resulting in heavy fabric weights), such balloons are able to utilise naturally shaped envelopes that require no additional pressurisation other than that resulting from the gas pressure head. These envelopes may therefore be of very lightweight fabric, enabling smaller overall size, reduced cost and improved handling ability.

Simple balloons, which just float in the air stream (moving with it), however, are not subject to such adverse conditions as would be experienced when there is relative airspeed. Also, their lack of stiffness makes it difficult to mount or operate thrust systems and their envelope surface does not adapt very well to mount solar power panels. Additionally, the gas expansion causes a significant envelope profile change as the balloon transits between ground level and the stratosphere; being at low altitude a

very long inverted tear drop (bulbous head with long vertical gathered and tapering tail) whilst at high altitudes reduces vertical length and fills out to a spherical shape. These aspects make them very difficult to adapt.

Lastly, solar power has been discussed above without explanation for its use. Any LTA vehicle able to attain the height required will take quite a long time to do this, through difficult circumstances and with similar aspects when returning to the ground, which should not be repeated unnecessarily. Users of the platform also will want their systems to remain on station for as long as possible (30 days or more). Large quantities of consumable fuels, if used alone, would therefore need to be carried adding weight that must be buoyed. This is an escalating effect on the resulting vehicle size that makes it unviable. Also, as the fuel is used, the gross weight reduces. The buoyancy or gas lift, however, remains more or less constant (depending on external environmental conditions) so would cause the vehicle to rise if thrust is not employed to counteract the accessional imbalance – otherwise the lifting gas must be vented to reduce buoyancy.

This is a common problem for airships, which normally counteract the imbalance with aerodynamic lift on the hull (as a lifting body). To generate aerodynamic lift airspeed and a means for pitch control plus a suitable lifting body shape are necessary, adding complexity and thus weight plus cost. Water recovery from the burnt fuel has been another way to maintain constant weight of the system. Regardless, these are features that this proposal seeks to obviate.

Solar energy, which can be harnessed via collector panels, provides a way to generate power at constant weight and should be available over long periods, so is a natural choice as the prime method for power generation. In the stratosphere there should be

little to interfere with this process although in the lower atmosphere with cloud cover and at night, a secondary means of power generation may be necessary. Provided that big enough solar panels can be installed with sufficient efficiency and batteries installed adequate to provide power through the night the system should be able to cope. Nonetheless, as backup and to serve needs for the payload systems other more conventional methods also may be employed. These, of course, would need to be able to operate in the stratosphere.

The present invention will now be described by way of an example, with reference to the accompanying drawings in which:

Figure 1 is a side view of a lighter-than-air vehicle constructed in accordance with the present invention showing the vehicle in a moored position;

Figure 2 is a side view of the vehicle of Figure 1 in a second moored position;

Figure 3 is a side view of the vehicle of Figure 1 in a pre-launch or post recovery position;

Figure 4 is a side view of the vehicle of Figure 1 showing the vehicle in a free flight position at low altitude;

Figure 5 is a side view of the vehicle of Figure 1 showing the vehicle in a free flight position in the stratosphere;

Figure 6 shows a plan view of part of the support structure of the vehicle of Figure 1.

Referring to Figures 1 to 6, the lighter-than-air (LTA) vehicle comprises an upper envelope assembly 1, a stiffening ring assembly 2, and a lower envelope assembly 3. In operation, the upper envelope assembly 1 is inflated with a lifting gas such as helium or hydrogen and the stiffening ring assembly 2 constitutes the main structural component of the LTA vehicle. The lower envelope assembly 3 provides a reserve compartment to contain the lifting gas from the upper envelope chamber 1 as it expands, mainly through ascent, and until contracting through descent or other climatic changes.

The basic components of the LTA vehicle are best seen in Figures 3 to 5.

The upper envelope 1 is made of a membrane 4 of gas impermeable flexible fabric that is attached in a gas-tight manner around its perimeter to the ring 2 at a location tangential to the upper outer quadrant of the cross-sectional diameter of the ring 2. A second membrane 5 of gas impermeable material is attached to the ring 2 below the upper membrane 4. The second membrane 5 provides the main outer boundary of the second envelope 3. A diaphragm 6 is attached to the ring 2 at a location between the first and second membranes 4 and 5. As explained below, the diaphragm 6 may either be permanently attached to the ring 2 and provided with controllable openings to allow lifting gas to flow into the second lower envelope 3 and return, or it may be detachable from the ring 2 after the LTA vehicle's assembly/inflation, prior to first ascent of the vehicle as will be explained in more detail later.

The membrane 5 is of a distended conical shape and is attached at its uppermost perimeter to the ring 2 in a gas tight manner. At the lowermost end of the second envelope 3 there is provided a lower ring 7 and a closing gaiter 8 connected between the lower ring 7 and the payload suspension system 10 so as to allow vertical

movement of the lower edge of the membrane 5 relative to the suspension system 10 as explained later. A payload capsule 9 is carried by a suspension system assembly 10 from the stiffening ring 2, as will be explained later. The lower ring 7 is interconnected with the capsule 9 by a tensioning line system 11 shown in figure 3, also as will be explained later.

The upper ring 2 is the main structural member of the LTA vehicle and comprises a toroid of normally 50 to 100 metres diameter having a circular cross sectional shape of typically 1 to 5 metres diameter. The upper ring 2 must be constructed so that it holds its shape, and provides a chassis on which the other components of the vehicle are mounted.

The upper ring 2 may be filled with the lifting gas (to help carry its weight), but it is not intended to be the main container of the lifting gas and it does not provide the main hull body. It is there primarily as a stiffening member. It also may act as a reserve chamber to store helium. It also is pressurised to a much higher level than that of LTA vehicle envelopes in general and of envelopes 1 and 3 here.

The tube of the upper ring 2 may be constructed as a conventional thin walled rigid shell, or made of pressure stabilised fabric membrane material. If the later, then a pressurisation system 12 will be needed to inflate the ring 2. A non-rigid pressurised ring 2 is preferred, since this will be more consistent with main envelope attachments, will be more flexible (to avoid damage under overload situations) and will enable delivery of the complete envelope fully assembled.

The lifting gas may be utilised as the medium for pressurisation of the upper ring 2, taken from the upper envelope chamber 1. As a relatively small cross-sectional

diameter tube, the ring 2 would be subject to high internal pressure compared with normal airship envelopes, since the resulting membrane stress is proportional to pressure and radius. Thus, whilst a typical airship envelope would be subject to about 500 Pa super pressure, the tubular ring 2 if of 2 metres cross-sectional diameter would need about 35,000 Pa (0.35 bar). As such, small atmospheric changes will have little effect (compared to effects on a normal airship envelope). The system 12 to accommodate this would be quite small, light and of low power consumption. This method may also serve as a means to adjust the buoyancy and accommodate the main envelope 1 gas volume changes by storing gas within the ring 2.

The upper stiffening ring 2 provides the main structure to support the other features. A secondary pressure means 13 to pressure stabilise the tubular form of the ring 2 will be necessary if it is of non-rigid form. Air may be used for this purpose, to avoid loss of the lifting gas from the main envelope chambers 1 & 3. This may be by an independent blower system 13 or via a valve and duct system to divert the flow (if there is primary blower redundancy). Pressure management of the stiffening ring 2 adopts similar methods to that for non-rigid airship envelopes, except that it must work at much higher pressures, so the blowers do not need to operate all the time (only to maintain pressure if the ring pressure falls).

The tubular ring 2 is fitted with internal bulkheads (not shown) that stabilise its form and which are used for attachment of other parts. Ballonets 14 also may be installed within the ring 2 to contain air for pressurisation. The upper ring 2 integrates with the thrust unit support structures 15 that are provided as hard structures, each with a pylon (not shown) to support the respective thrust units 16.

Integration of the tubular ring 2 with the hard structure 15 may be by simple clamp ring techniques. This is not the only way but is a simple and reliable technique known to work. The bulkheads within the ring 2 also may be of fabric materials and should freely allow the passage of gas (& people) between each cell. The ring 2 provides the mounting points for radial support ties 17 (of the suspension system assembly 10) that connect to a central vertical suspension line 18 (described later), and for mooring and handling lines 19, 20. The bulkheads within the ring 2 would be used to transmit load from the radial support ties 17 and the mooring & handling lines 19, 20.

The upper envelope assembly 1 provides the main chamber region for the lifting gas and is subject to gas pressure head only. As such it can be made from reasonably lightweight fabric, since it is not a main structural item. The upper ring 2 is used to carry such structural loads. In addition, the upper envelope 1 provides the mounting surface for solar energy collector panels 21. It is expected that the whole upper surface of the envelope 1 would be covered with solar panels 21, separated from the membrane 4 by an insulating layer (not shown) to reduce heating effects and to protect the envelope 1 from direct environmental effects.

After inflation, the upper envelope 1 is expected to be permanently filled with lifting gas due to natural effects that cause the gas to settle in the upper chamber. As such its shape is unlikely to alter very much, so should be stable and therefore suitable to mount the solar panels 21. A shallow domed shape with large radius is envisioned, since that is all that should be necessary to contain the lifting gas charge at ground level. If stiffening is required, then secondary inflatable radial tubes (not shown) extending from the main stiffening tube 2 and filled with the high pressure gas may be used for this purpose, providing ribs. However, it is unlikely that this will be necessary.

Electrical lines (not shown) from the solar panels 21 will be led away via conduit routes (not shown) around the main stiffening tube 2 to the thruster support structures 15, where it is expected that main electrically driven power system components and batteries (not shown) will be installed.

The membrane 5 of the lower envelope assembly 3 connects at its upper end to the outer surface of the stiffening ring 2 at a tangent position when inflated via a continuous gas tight joint similar to that of the upper envelope 1. This joint is expected to be just below the stiffening tube's 2 equator position, such that the fabric weight hangs freely without causing peel effects and can wrap around the tube's 2 outer lower quarter segment. The lower envelope assembly 3 is expected to be almost, if not fully, collapsed at ground level. It provides the large expandable chamber region for the lifting gas to expand into and is only subject to gas pressure head effects when the lifting gas expands into it. As such it can be made from very lightweight fabric.

At ground level it is expected that the lower envelope 3 would be drawn in by atmospheric effects when lifting gas is compressed to its original volume by atmospheric pressure to resemble a dangling tail as shown in Figure 3. This is normal, and will allow the main tail to be moved to one side as shown in Figures 1 and 2, further allowing the upper envelope 1 and main stiffening ring 2 to be held with its mooring lines 19 near to the ground (without affecting lower end features).

The mooring lines 19 will connect at bulkhead positions to the main stiffening ring 2 between the upper and lower 4 and 5 membrane joints. These can be used early in the assembly of the vehicle and during inflation sequence, enabling in-field build arrangements without a hangar. Whilst twelve positions are shown, this is only illustrative (to show the principal). Although twelve is a reasonable number (providing

redundancy against failures) the actual number of attachments should be decided from a formal analysis taking account of failure aspects.

Ability to hold the vehicle close to the ground in a stationary manner and permit construction without a hangar are significant benefits compared with current airship practices. These aspects will aid deployment of the vehicle over wide regions, reduce maintenance costs plus difficulties and enable severe storm conditions to be endured. The arrangements also facilitate decommissioning for transport to another site or back to a hangar for repair work.

The shape of the lower envelope 3 when fully filled by the expanded lifting gas is expected to be a distended cone as shown in Figure 5. Other shapes are possible, including completion of the upper envelope 1 profile to result in a sphere. This would affect the joint position and the placement of the trust units 16, but not the overall concept. Final shape may therefore be decided by the developer.

The lower ring 7 is fitted at the lower edge of the envelope 3 to reinforce and maintain a constant circular lower edge profile, and provide means to interconnect via a tensioning line system 11 with the payload capsule 9. The payload capsule 9 is itself supported via an independent suspension system assembly 10 from the main stiffening ring 2, obviating effects due to lifting gas expansion and contraction. Arrangement of the suspension system assembly 10 is as follows. Radial support ties 17, similar in concept to the spokes of a bicycle wheel, extend from the bulkhead connection points of the main stiffening ring 2 to an upper central hub 22. From there, a long vertical suspension line 18 descends to a lower support hub 23 above the capsule 9. Short suspension lines 24 descend from the lower support hub 23 to connect the capsule 9 at its interface points. Conduit may also follow this route to provide necessary power,

signalling and control over the upper mounted systems thus guaranteeing that line lengths can be maintained. The tensioning lines 11 attached to the lower ring 7 are connected to the capsule 9 via a spring reel (not shown) mounted on the capsule 9 to enable them to be retracted, thereby to pull gently the lower ring 7 into position on top of the capsule 9. The gaiter 8 connected between the lower ring 7 and the hub 23 allows for vertical movement of the ring 7 relative to the hub 23. This is necessary since, when the lower envelope 3 collapses due to contraction of the gas as the vehicle descends, it is expected that the lower envelope 3 will draw up as shown in Figure 3. In reverse, as the vehicle ascends the lower envelope 3 will extend downwards as shown in Figure 4 until the lower ring 7 sits on the capsule 9. It will then fill out as further gas expansion occurs. These simple features should maintain alignment in a stable way, freely allowing the shape of the lower envelope to change without affecting the capsule's suspension or control and signal lines' length (between the capsule and upper envelope), yet providing a secondary load path for capsule support and stabilisation under abnormal circumstances.

The payload suspension system 10 parts may be made using existing materials and parts that generally are stock items, although some parts (such as hubs 22, 23 and attachment brackets) may need to be developed to suit. Careful attention to the selection of materials and the detail arrangements will be necessary to avoid damage due to lightning strikes. Nonetheless, development and construction would follow normal aircraft practices, so do not need elaborating in any detail here.

Vertical load from the payload capsule 9 is carried to the upper central hub 22 and thence via the shallow angled radial support lines 17 to the stiffening ring 2. With a shallow angle, a single line 17 from each side to support the central vertical line 18 would generate high load. However, by utilising several pairs of support lines 17 in

such a radial fashion the load may be spread equally between them, enabling a high vertical suspension load to be supported centrally without high loads being generated in the upper support lines 17. Each support line 17 therefore applies an inward load on the stiffening ring 2 that must be reacted. The load initially is carried by the bulkheads of the stiffening ring 2, which in turn transfer the load in shear and tension to the stiffening ring tube 2. The radial loads cause compression across the section of the stiffening ring 2 that resists the line 17 forces. As a flexible fabric structure, this compression is resisted through the stiffening effect of its pressurisation, thus enabling the support without significant change to the overall geometry.

A further additional feature that may be considered is the addition of a rigid pole (not shown) from the upper central hub 22 vertically upwards through the mid point of the membrane 4 of the upper envelope 1. If the membrane 4 is provided with fittings and a gaiter (not shown) at this position to seal the penetration, the pole may be held from toppling by the membrane 4 and used as a mast mounting above it for other purposes. Such purposes could be to: mount instrumentation, a flag, lights, lightning protection facilities, observation cameras, a telescope, an upper protection canopy (perhaps, whilst moored, to keep snow off the solar panels or to use as an insulation layer to maintain an even gas temperature through day and night), transmitter/receiver equipment, a radar antenna. Vertical loads from the pole would be carried by the suspension system 10. The axial feature may also be used as a route for conduit lines.

As described above, the lower envelope 3 at its bottom edge is terminated by a ring 7. This leaves the envelope 3 open at the bottom with the possibility that the expanding lifting gas in the space bounded by the lower membrane 5 could be vented. Whilst this is unlikely, the aperture should be closed by a further fabric gaiter 8 (conically shaped) and fitted between the envelope's lower ring 7 and the capsule suspension system's

lower hub 23. This gaiter 8 would flex inside out and back again as the lower envelope 3 moves up and down respectively. The gaiter 8 also would need a non-flexible portion next to the support hub 23 for bulkhead connectors (to enable the control and other conduit lines to pass through).

It will be appreciated that the capsule 9, with its payload and necessary systems will be reasonably heavy and is under slung at a very low position below the upper structure 1, 2, 3. Also, the lower envelope 3 provides weight that is fairly low. These masses should provide strong pendulum stability to keep the essentially lenticular upper structure shape (when at low altitude) from behaving aerodynamically in an unstable manner. When the lower envelope 3 fills out (at high altitude) this would no longer be a problem. Nonetheless, if it is found to be a problem, further lines (not shown) could be installed directly between the main stiffening ring 2 and the capsule 9 to obviate any flexure of the lower envelope – forcing the whole arrangement to behave as a single body. Alternatively, the long handling lines 20 could be connected to the capsule 9 to undertake this function. A disadvantage of these line connections is that they would interfere with the free expansion of the lower envelope. Since solutions exist and this is thought to be not a problem, there is no need to discuss it further.

The handling lines 20 can be extension parts connected to the lower ends of particular mooring lines 19 that enable the vehicle to be restrained whilst fully extended (as shown in Figure 3). This normally only would be prior to a launch or after capture. The lines would be used with winch gear (not shown) to haul down or let up the upper inflated structure 1, 2, 3 against buoyancy to a height where the mooring lines 19 may be connected as shown in Figure 2. When properly secured by all of the mooring lines the capsule 9 and lower envelope 3 tail should be carefully moved to one side out of the way. The upper inflated structure 1, 2 should then be hauled right down to its

lowest level and re-secured by the mooring lines 19 (as shown in Figure 1) to hold it safely against adverse weather.

Capture (the recovery action, when the vehicle is first caught by the ground crew and connected to a ground anchor) and Launch (the release action, when the vehicle is finally let go by the ground crew from its last anchor point) are facilitated by a single line 25 below the capsule 9. This line 25 is used to pull down the floating vehicle to the ground and then tie-off to hold it in position. This action probably can be undertaken using manpower effort assisted by the vehicle thrust units 16 and will require a central mooring site anchor fitted with a ring (not shown) to pass the cable through and a tie-off point to one side (not below the capsule), which also can be a ring on a ground anchor. Once captured, the handling lines 20 would be connected followed by haul down of the upper structure 1, 2, as described above. When restrained by the handling 20 and mooring lines 19 the recovery/release line 25 would be disconnected from the anchors to permit movement of the capsule 9 to its side parking position.

If needed, for whatever reason, the recovery/release line 25 also may be used to move the vehicle to a new position using a floating technique, where the vehicle is connected to a heavy surface mover (tug or tow vehicle) then ballasted to a light condition (where buoyancy exceeds gross weight) to maintain line 25 tension and finally towed to its new position. This could be necessary if the vehicle is unable to return to its ground station for recovery purposes. The handling lines 20 also may be used for this purpose with additional surface movers to provide restraint during the transit.

The recovery/release line 25 also must be able to discharge static electricity from the vehicle to ground. Procedures will be necessary during capture or launch that personnel do not handle the lines 19, 20, 25, until static discharge has occurred. This

will necessitate the line touching the ground before the ground crew recover the line. The line 25 also may be used as part of a lightning protection and discharge system. The particular arrangements for lightning strike protection are within the capabilities of persons skilled in designing such systems.

The payload capsule 9 is the housing for the payload and the vehicle's main systems, such as: Electrical, Control, Avionic, Pressurisation, Fire Detection and Suppression, Environmental Control, Auxiliary Power, Ballast and Miscellaneous Equipment. These are all typical of airship and other aircraft installations, so do not need elaborating in any detail here. It is expected that existing technology would be adapted and used to fulfil the needs. The payload capsule 9 itself is envisioned to be constructed as a vertical cylinder with dished upper and lower end caps, as a pressure vessel. It would be provided with a floor, ceiling, windows, doors and interface positions suitably reinforced and stiffened as necessary to suit the purpose. It is expected that it may need to be pressurised to provide the necessary environment for the payload. Its development and construction would follow normal aircraft practices, so do not need elaborating in any detail here.

Since the payload capsule 9 could be damaged when the vehicle returns to the ground, fenders (not shown) would be necessary. These could be obviated if the operator is confident enough, but this is not recommended. Various types of fender may be used, such as: bumper, pontoons, wheeled shock absorber legs, skids, etc, to suit the operational circumstances. The preferred choice is a sprung skid arrangement (not shown) at three positions around the capsule 9 that use a large rotating dish as the skid (similar to some castors) and acting as legs to support the capsule 9.

For control of the vehicle ducted propeller thrust units 16 driven by electrical motors behind a propeller are used. The propeller itself should have variable blade pitch angle control to enable varying amounts of thrust both forward and rearwards to be developed. This also will be necessary to suit the different environments from sea level to the stratosphere and to provide precise control, particularly during launch and capture.

Power for the motor would be drawn from the electrical installations housed in the thrust unit support structure 15, as discussed above. Additional small and self contained auxiliary power units (not shown) may also be installed in the thrust unit support structures 15, to overcome short term needs if the solar panels 21 and their accumulators (batteries) are unable to provide sufficient supply (perhaps at night).

Whilst just two thrust units 16 are shown in the figures, the minimum for correct functioning, further units could be installed (improving failsafe aspects). This however, does not alter the concept. These arrangements are similar to those already developed for other uses – except that they must be able to perform adequately in the stratosphere.

In order to control the vehicle in any direction each thrust unit 16 would be provided with a vector system (not shown) to rotate the duct for alignment of the thrust, as desired. Several airships and other aircraft have used such mechanisms for similar purposes, so this does not need to be elaborated.

In addition to thrust control other controls will be necessary, such as:

- ballast dump – to reduce weight

- helium valves – to reduce aerostatic lift
- envelope rip or holing system – to destroy aerostatic lift.

These are standard airship features, the particular arrangements of which will be within the scope of knowledge of persons skilled in the art.

Navigation lighting (not shown) and a transponder (not shown) will also be necessary, to comply with the Air Navigation Order. These are mandatory, the particular arrangements of which will be within the capabilities of persons skilled in the art.

At the height of operation in the stratosphere, the vehicle is unlikely to be a hazard to most aircraft. It probably will not have an easily detectable radar signature, so the vehicle should be provided with a radar reflector to enable tracking if circumstances (such as total power failure) could occur where the transponder and GPS system cease to function. If total power failure does occur, as an LTA vehicle, it should continue to float in the stratosphere but will drift with the prevailing air currents. Ultimately, the vehicle will need to be brought down under controlled circumstances and before conditions deteriorate – causing it to come down unexpectedly. Emergency backup batteries therefore should be provided that have the sole purpose of providing power to operate those systems necessary to bring the vehicle down under controlled conditions.

To bring the vehicle down under these circumstances it will be necessary to operate a valve to release some of the lifting gas, so that it will descend due to static heaviness (when gross weight exceeds buoyancy). A means to arrest the descent by opening another valve to dump ballast, making it statically light, also will be necessary. Finally, when it is known that it can descend safely to a suitable resting place a means to

release quickly all of the gas will be necessary so that it does not take-off again or drift across the ground. A means to hole the envelope should be provided for this purpose. Clearly the vehicle will need to be recovered from its final resting place. If the descent procedure is undertaken with due care, there will be no permanent damage and the vehicle plus the payload should be able to be recovered intact for subsequent operation.

The diaphragm 6 is a disc (circular membrane) of light gastight material (envelope fabric) that connects continuously to the inner facing wall of the main stiffening ring 2 (probably at its equator level) at a position just above the capsule suspension system's 10 radial support lines 17 to close off the upper chamber 1.

Prior to filling the upper envelope 1 with lifting gas, the upper envelope 1 and stiffening ring 2 are filled with air and necessary operations to inspect, make good, test and assemble parts that will be inaccessible later are carried out at this stage. The solar panels 21 (if not factory fitted) and their backing insulation, valves, lights, instruments, reinforcements, helium fill fittings and all other upper envelope parts should be fitted. In addition conduit and systems lines should be routed/fixed in place.

The payload capsule upper suspension parts including: radial support lines 17, upper support hub 22 and the vertical suspension line 18 should also be assembled and installed at this stage from the inner face of the stiffening ring 2. Suspension system 10 parts previously should have been proof tested by tensile testing to a level that guarantees their integrity for operation and removes any slack to reduce line length changes in operation.

In order to get into the upper 1 and lower 3 chambers, suitable manhole positions plus aperture reinforcements will be needed in the upper envelope 1 and inflation diaphragm 6. These must be closed and sealed before lifting gas inflation.

If the suggested upper mast pole is to be adopted this also should be installed, plus any associated systems it is intended to carry. The inflation diaphragm 6 will be needed for subsequent lifting gas fill operations, so a means to connect the pole to the upper support hub 22 with the diaphragm 6 between that can be sealed will be necessary. Also, when the air is exhausted from the various chambers 1, 2, 3 prior to gas inflation, the upper envelope 1 needs to be able to collapse completely without restriction from the pole. A sealing sleeve from the upper envelope penetration fitting to the upper support hub will be needed for this, also enabling the pole to be removed without gas loss.

To undertake assembly and inspection work in the lower envelope 3 chamber before lifting gas inflation it will be necessary to raise the upper structure 1 and 2 from the ground. This is done by closing all upper envelope 1 apertures, leaving an aperture in the inflation diaphragm 6 open, slackening the mooring restraint lines 19 and then blowing more air into the upper chamber 1 allowing air to transfer to the lower chamber 3. The vehicle will then rise supported by the lower envelope 3 as an air cushion. This will permit internal/external inspection of the upper portion of the lower envelope 3 for pin-hole damage plus basic integrity and conformance. Any non-conformance aspects must be corrected before inflation with the lifting gas. The height should not be taken too far, since the arrangement at this stage will be top heavy – so will need the mooring lines to restrain it from rolling. Manhole penetrations in the lower envelope for access purposes also will be needed for personnel to undertake this work. These also must be closed and sealed before lifting gas inflation.

When the work necessary on the upper part of the lower envelope 3 has been completed, its manhole covers should be finally fitted and then the air allowed to exhaust through the upper envelope 1 by simply removing a cover (allowing the air to exhaust) until the main stiffening ring 2 is seated once more on the ground, taking care not to damage the manhole covers beneath in the process. Systems checks, as far as possible should be undertaken to confirm correct operation.

When all the above inspection, correction, assembly, and checkout work has been completed, preparations for gas inflation should be undertaken. Air does not need to be exhausted from the lower chamber 3, since this can be a useful cushion to support the upper envelope 1, so the manhole in the inflation diaphragm 6 should be finally closed. Following this, plus the removal of all equipment and personnel from inside, all air should be evacuated from the upper chamber 1 and the main stiffening ring 2, as necessary, causing the assembly to collapse flat against the ground (except for the cushion of air trapped in the lower envelope chamber 3).

Following removal of the ground blower system tubes all apertures and manhole positions must be finally closed. It will be useful if these apertures are provided with sleeves that can be quickly tied off to arrest any flow before installing the covers. Lifting gas inflation preparations should follow.

The lifting gas may be helium or hydrogen depending on circumstances of acceptability. Hydrogen is a highly inflammable gas whilst helium is inert. However, helium is a rare gas that is very expensive and does not provide such good lift characteristics as hydrogen.

When the lines 19, 20 to restrain the vehicle have been checked and adjusted to suit, the gas plant positioned, the inflation pipes connected to the upper envelope 1 and the main stiffening ring pressurisation system 12 primed (ready to transfer gas from the upper chamber to fill the tube 2), gas inflation may commence. Gassing should proceed at a steady rate whilst monitoring the behaviour. It is expected that a bubble will rise from the upper envelope and gradually spread out until the upper chamber 1 is filled. In addition, as gas transfers to the main stiffening ring 2 this also should rise until it is full. No net, sandbags or other devices, as used in small gas balloon inflations, are expected to be necessary – the mooring system 19, 20 being all that is necessary for restraint. When the upper envelope 1 is filled, the plant may be disconnected and removed. A small reserve of gas should be kept at the site for subsequent topping up. Monitoring of the system (pressure watch) will be necessary from this time onwards. Also, tension in the mooring lines 19 will have increased, so this should be checked and adjusted to maintain a balanced system.

Inflated with its lifting gas (trapped in the upper chamber 1 by the inflation diaphragm 6) subsequent operations that require work inside the lower envelope 3 may be safely conducted in an air environment. The inflation diaphragm 6 should function as a ballonet membrane to accommodate gas expansion through its distension. Otherwise, pressure may be increased in the main stiffening tube 2 to draw off gas from the upper chamber 1. Buoyancy may now also be used to raise the upper structure 1, 2, 3 for subsequent work.

Completion of assembly work should follow with installation of the thrust units 16, followed by functional checkout of the systems involved. If the structure 1, 2, 3 needs to be raised for this then the handling systems 20 should be used to do this, allowing buoyancy to lift the upper structure 1, 2, 3 to the height desired as the lines 20 are paid

out. Also, if the solar panels 21 were not installed this should be completed. When assembly work is complete the upper structure 1, 2, 3 may be let up sufficiently, restrained by the handling lines 20, to enable lower end work to be undertaken.

The payload capsule 9 is a self contained system the assembly work of which can be undertaken in parallel with the envelope 1, to inflation, so that it is ready for integration when the envelope 1, 2, 3 work is complete. It also is envisioned that the capsule 9 would be factory completed to a fairly high degree before site delivery. Delivery of this capsule 9 is expected to be on a maintenance cradle that can be removed after the ground fenders are installed. After installation of the fenders and removal of the cradle, the capsule 9 should be able to be freely moved and be free standing on the fender legs without need for anything further.

After the system has been let up, the lower envelope 3 (open at this stage at the bottom) and the payload capsule vertical suspension line 18 will hang down freely in a natural way from their upper attachments – the lower envelope 3 partially filling with air through the bottom aperture. When things have settled, inspection of the lower envelope 3 to the height previously unchecked internally/externally for pin-hole damage, basic integrity and conformance should follow. Any non-conformance aspects should be corrected before closing the lower aperture. To facilitate this work the structure should be gradually lowered or raised using the handling restraint line 20 winches so that work can be conducted at ground level.

Final assembly work, to fit the lower end components and interconnect with the payload capsule 9, is the last thing to do to complete the vehicle. After installing the suspension system lower support hub 23 and the payload capsule suspension lines 24, using clamp plates, the lower envelope 3 bottom edge ring 7 and the conical closing

gaiter 8 should each be installed. The payload capsule 9 can then be connected to the suspension system 10 via its lower lines 24 and the lower envelope interconnected by the tensioning lines 11. System and control lines finally may be connected to complete the vehicle.

At this stage the lower envelope 3 will be partially full of air that needs to be evacuated. Before this is done, a leak and proof pressure test of the lower envelope 3 using air should be conducted to demonstrate integrity for operation. The ground blower therefore needs to be installed and used to fully inflate the lower envelope chamber 3 with air and to pressurise it. This check also will enable the final fit to be assessed – to determine that the arrangements will function correctly during operation. Air put into the lower envelope 3 will not mix with the already gas inflated upper chamber 1 because of the inflation diaphragm 6. This diaphragm 6 also will keep the gas from escaping when the lower envelope 3 is evacuated.

Having checked the lower envelope's 3 integrity, the ground air blowers should then be set in reverse to evacuate all of the air from the lower envelope chamber 3. During this stage the lower envelope 3 will draw together and rise (as shown from figures 5 to 3) due to atmospheric pressure action. As the air is evacuated the arrangements should be checked to determine that the gathering and rising action occurs as expected, without causing any problems. Following air evacuation, the ground blower system should be removed and the aperture finally closed. For convenience this aperture should be near the bottom of the lower envelope 3, be fitted with a sleeve (used to close it) and be of a flexible reinforced type with fabric covers that are then tied together to keep the sleeve inside.

At this point the vehicle is nearly ready for operation. However, before this is undertaken, the inflation diaphragm 6 either must be removed or a means to allow the lifting gas to expand into the lower chamber 3 must be provided. Removal will be awkward to undertake and, although it enables weight to be saved, could be a useful feature for future use. Uses could be as follows:

- As a secondary container membrane to prevent all of the lift gas being lost should there be leakage from the upper envelope 1 – a possibility if a dump valve were to stick or fail in the open position.

- As a means to raise the upper compartment pressure – a need may exist for this if the gas head is insufficient to stabilise the upper envelope 1 membrane 4 for a) maintenance activities (to allow people to walk on the upper envelope 1) or b) operational reasons (if it is found that a higher pressure is needed).

- For future maintenance and inflation purposes.

If, for these or other reasons, the inflation diaphragm 6 remains as a permanent feature then it will need valves that can be remotely operated to open and to remain open through operation until deliberately set to close. Indeed, the failsafe action for these valves should be that they would only fail in the open position. This will then permit the free expansion of the gas. Sizing, position, method of operation and number of valves will be for the developer to decide. Also, procedures for the use of these valves will be necessary to ensure there is free passage for the gas to pass through between the upper 1 and lower chambers 3.

To launch the vehicle the following outline procedure will be necessary.

It is assumed that the vehicle is in its fully moored position as shown in Figure 1 with the payload capsule parked to one side. If not already inflated fully with lifting gas, chamber 1 is topped up with lifting gas pumped under pressure into the upper chamber 1. If not already evacuated the lower chamber 3 is evacuated of air as described above. The mooring lines are released in a controlled way and as the vehicle ascends under remote control from the ground it is flown to a desired geostationary location. During ascent and descent the venting means in diaphragm 6 are controlled to allow lifting gas to expand into the lower chamber 2 or contract into chamber 1.

Recovery of the vehicle largely is a reversal of the above procedure, so does not need to be elaborated in detail here. In general terms, the ground pilot will set-up the vehicle for its descent applying normal LTA practices and bringing it to an overhead position above the mooring site. Prior to capture, a weigh-off will be conducted to set the state of equilibrium (static heaviness or lightness) for capture. Whilst the ground pilot controls position and height of the vehicle relative to the mooring site the Crew Chief will coordinate and control ground operations. After touch down of the recovery/release line 25 (to discharge static electricity) a crew member will collect the line 25, connect it through the ground anchor ring at the centre of the mooring site, lead it out and then tie it off at its side restraint position. At this point the vehicle is 'Captured' as shown in Figure 3, but without the handling lines 20 connected, and the Crew Chief assumes control for subsequent actions.

CLAIMS

1. A lighter-than-air vehicle comprising; a structural ring member having attached around a perimeter thereof a first flexible gas impermeable membrane, a second flexible gas impermeable membrane, and a diaphragm that, at least temporarily, is located between the first and second membranes to define an upper chamber that is inflatable with a lifting gas bounded, at least in part, by the first membrane and the diaphragm, and a lower chamber bounded at least in part by the second membrane and the diaphragm, said diaphragm being either removable after the upper chamber is inflated with a lifting gas but prior to the first ascent of the vehicle, or having venting means for allowing the lifting gas in the upper chamber to expand and pass through the diaphragm during ascent of the vehicle, thereby to allow the lifting gas to expand into the space bounded at least in part by the second membrane; and a payload capsule suspended from the structural ring member.

2. A vehicle according to claim 1, wherein the structural ring member is a hollow inflatable structure.

3. A vehicle according to claim 2, wherein the structural ring member is a hollow rigid structure.

4. A vehicle according to claim 2, wherein the structural ring member is a flexible structure.

5. A vehicle according to claim 4, wherein the structural ring member has internal bulkheads.

6. A vehicle according to any one of the preceding claims, wherein the first membrane forms a dome shape when inflated.

7. A vehicle according to any one of the preceding claims, wherein the second membrane is of a distended conical shape and is attached at an upper end around a circumference of the structural ring member.

8. A vehicle according to any one of the preceding claims, wherein the second membrane is provided with a lower ring member attached to a lower end of the second membrane.

9. A vehicle according to any one of the preceding claims wherein a payload capsule suspension system is provided comprising tie members that extend in a radial direction from the structural ring member to an upper hub assembly, and a downwardly directed tie member that extends vertically from the upper hub assembly, and the payload capsule is connected to a lower support hub attached to the lower end of the downwardly directed tie member.

10. A vehicle according to claim 9, wherein the lower ring member is moveable vertically relative to the downwardly directed tie member.

11. A vehicle according to claim 10, wherein the payload capsule is attached to the lower ring member by way of retractable tension lines that urge the lower ring member towards the payload capsule.

12. A vehicle according to any one of claims 8 to 11, wherein a gaiter is provided between the lower ring member and the lower support limb to allow vertical movement of the lower ring relative to the lower support limb.

13. A vehicle according to any one of the preceding claims wherein the diaphragm is connected to the structural ring member by a joint that enables the diaphragm to be removed prior to the first ascent of the vehicle.

14. A vehicle according to any one of the preceding claims, wherein the diaphragm is provided with controlled venting means for allowing lifting gas from the upper chamber to expand and flow through the diaphragm into the lower chamber in a controlled manner.

15. A vehicle according to any one of the preceding claims, wherein propulsion means are connected to the structural ring member.

16. A vehicle according to any one of the preceding claims, wherein solar power panels are located on the upper membrane.

17. A vehicle according to any one of the preceding claims, wherein a mast is provided that projects upwardly from the upper membrane of the upper chamber.

18. A method of launching a vehicle constructed in accordance with any one of the preceding claims, the method comprising securing the vehicle to the ground by mooring lines inflating the upper chamber with a lifting gas that is lighter than air, evacuating the lower chamber to provide a volume for receiving expanded lifting gas from the upper chamber, and releasing the mooring lines.

19. A method according to claim 18, including the steps prior to inflating the upper chamber with the lifting gas of inflating the upper and lower chambers with pressurised air so as to raise the structural ring member and the upper chamber from the ground, and subsequently evacuating the upper chamber of air.

20. A lighter-than-air vehicle substantially as hereinbefore described.

21. A lighter-than-air vehicle substantially as hereinbefore described by reference to or as illustrated in any one of Figures 1 to 5.

22. A method of launching a vehicle constructed in accordance with any one of claims 1 to 17 and substantially as hereinbefore described.

ABSTRACT

A lighter-than-air vehicle comprising a structural member (2) in the form of a toroidal ring having attached around a perimeter thereof a first flexible gas impermeable membrane (4), a second flexible gas impermeable membrane (5), and a diaphragm (6) that, at least temporarily, is located between the first and second membranes (4,5). An upper inflatable lifting chamber (1), bounded at least in part by the first membrane (4) and the diaphragm (6), is inflatable with a lifting gas. A lower chamber (3), is provided. This chamber (3) is bounded at least in part by the second membrane (5) and the diaphragm (6). The diaphragm (6) is either removable after the upper chamber (1) is inflated with a lifting gas but prior to first ascent of the vehicle, or it remains in place and is provided with means for allowing the lifting gas in the upper chamber (1) to expand and pass through the diaphragm (6) during ascent of the vehicle. This allows the lifting gas to expand into the space bounded at least in part by the second membrane (5).

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November 4, 2003

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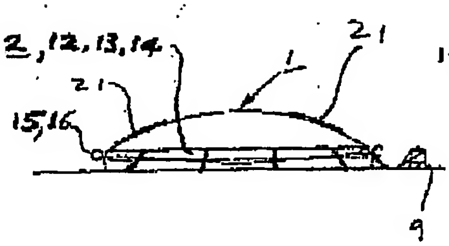


FIG 1

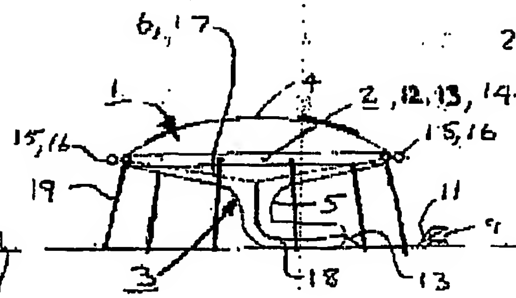


FIG 2

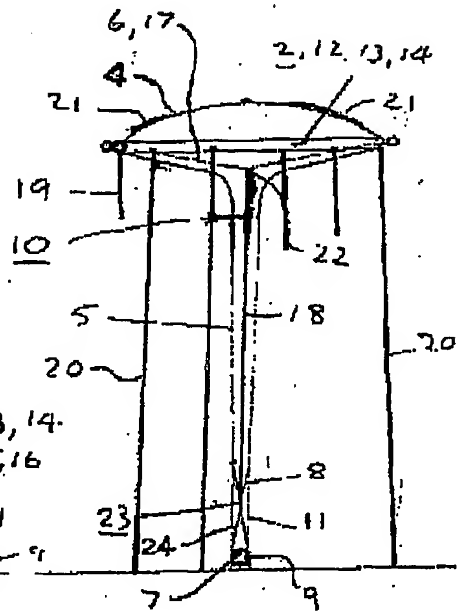


FIG 3

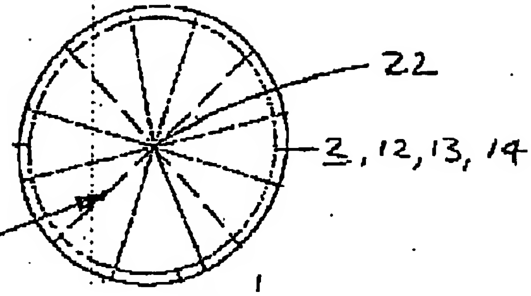
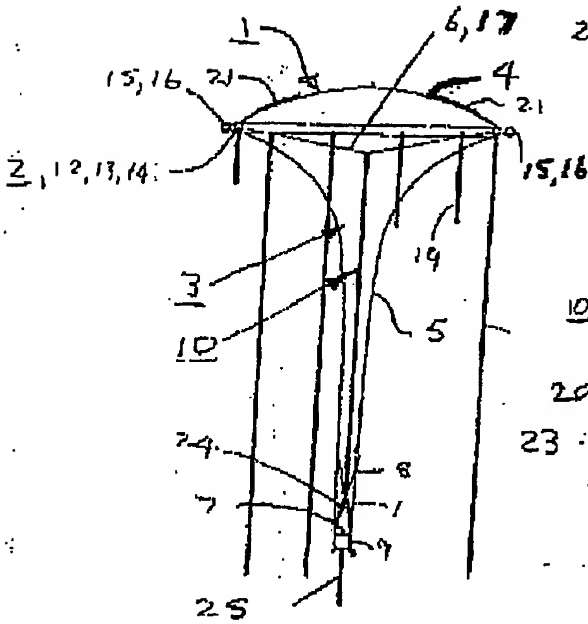


FIG 6



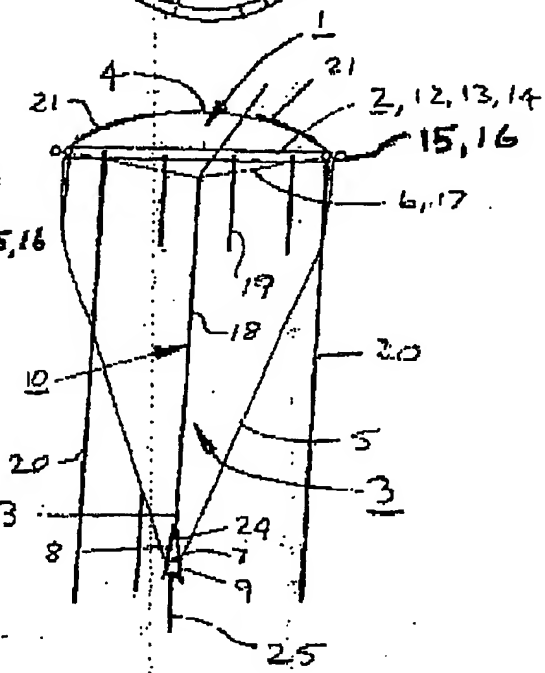


FIG 4

FIG 5

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